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TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 307

PRELIMINARY INVESTIGATION OF THE EFFECT OF A ROTATING CYLINDER IN A WING.

By E. B. Wolff.

From Report A 96 of the "Rijkstudiedienst voor de Luchtvaart," Amsterdam, reprinted from "De Ingenieur," No. 49, December 6, 1924.

March, 1925.

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Summary

Into the leading edge of a wing with arbitrary cross-section, there is introduced a cylinder, which can be rotated by an electric motor by means of a cord (Fig. 1).

Observations were made in the wind tunnel on how the lift at different wind velocities was affected by rotating this cylinder. In these preliminary tests the direction of rotation was from the pressure side to the suction side of the cross-section.

1. Object of the investigation.- Experiments by Joukowsky, Bjerknes and Ackeret** demonstrated that a rotating body disturbed

*Report A 96 of the "Rijkstudiedienst voor de Luchtvaart," Amsterdam. Reprint from "De Ingenieur," No. 49, December 6, 1924, pp. 57-66.

**Joukowsky, "De la chute dans l'air de corps légers de form allongée, animés d'un mouvement rotatoire," Bulletin de l'Institut Aérodynamique de Koutchino, No. 1, p. 51.

Bjerknes, "Zur Berechnung der auf Tragflächen wirkenden Kräfte" in "Vortrage aus dem Gebiete der Hydro- und Aerodynamik" (Innsbruck, 1922) p. 59; published by Von Karman and Levi Civita.

Bjerknes, "Die hydrodynamischen Fernkräfte und deren Zusammenhang mit den Auftriebskräften, die die Aeroplane tragen;" "Uittreksels der voordrachten Internationaal congres voor Technische Mechanica" (Delft, 1924), p. 98.

Ackeret, "Discussie van laatstgenoemde voordracht (not yet published).

Ackeret, "Neue Untersuchungen der Aerodynamischen Versuchsanstalt," W.G.L. Report in Z.V.D.I., October 11, 1924, p. 1086.

the surrounding medium in such manner as to exert certain definite effects on the body.

At the Delft Congres for Technical Mechanics, a simple experiment was performed by G. D. Boerlage with a paper cylinder, showing that such a cylinder, rotated about a horizontal axis, met an air force, which deflected it from its course.

It can, however, be expected that a rotating cylinder or flat plate, such as was used in the above-mentioned experiments, would have a drag proportional to the lift, as the result of the eddy formed behind the body. Since, however, great values of the lift coefficient could be obtained in this manner (Ackeret), it was important to try to obtain a smaller drag, by placing behind the cylinder a more or less streamlined piece, which prevented the formation of a great region of eddies. This imparted a wing shape to the body.

The question of the flow about such a body and the effect produced on the latter by the rotation of the cylinder can, however, be regarded from an entirely different viewpoint. It is assumed that, in fluids of small viscosity (including air), the effect of the viscosity is limited to a very thin layer, the so-called "marginal layer," in immediate contact with the body. This layer plays indirectly a very important part, in that it is the cause of the separation of the flow from the body, whereby vortices are formed which change the whole flow picture. This separation occurs, whenever the momentum of the marginal layer of air, diminished by fric-

tion, is no longer able to overcome the pressure increase along the body and produces a backward flow in the marginal layer. At small angles of attack, this occurs near the trailing edge of the wing. With increasing angles of attack, this separation point moves forward, until, in the neighborhood of the critical angle, the flow separates over so great a portion of the upper surface, that its character is entirely changed and the lift begins to decrease. The cylinder may now be considered as a means of increasing the momentum of the marginal layer, whereby the separation can be influenced. This can be a great help in the closer study of the flow about wings, all the more since the momentum imparted to the marginal layer in a given case can be varied almost at will by simply varying the rotation speed of the cylinder.

In the first trial of this experiment, the attention was devoted principally to the practical side of the problem, to increasing the maximum lift of an airplane wing and to other technical applications possibly proceeding from this. In continuing them, however, it should be borne in mind that important theoretical results can also be obtained.

For lack of information in this respect, some idea had first to be formed of the magnitude of the changes which could be effected in this way. Hence a simple wooden model was made and provided with a metal fore-piece in which the cylinder revolved about two pivots and thus constituted the entire leading edge of the model.

For simplification, it was decided, in these preliminary ex-

periments, to measure only the lift, since the possible increase in this was the most important practically. Hence the experiments were prepared and performed with this object in mind.

2. Description of model and method of suspension.- A cylinder of 37.5 mm (nearly 1.5 in.) diameter was mounted on pivots in a metal fore-piece, so that it could be rotated. To the same fore-piece there was fitted a removable rear-piece of polished wood, so that the whole formed a wing model (Fig. 1). Since there were no data known concerning the effect of such a cylinder on a wing, the rear-piece was constructed arbitrarily out of an available wing model. The cylinder was accurately balanced and the wooden portion smoothly polished.

The model was hung in the inverted position on streamlined tubes and connected with a balance above the wind tunnel. The stability of the whole was secured by means of wires (Fig. 2).

The 1/8 HP. electric motor was attached to the balance and its weight was offset by an upper auxiliary balance. The motor drove the cylinder by means of a fine cord. Thus the equilibrium could be affected only by a vertical force, which could be measured.

A white paint spot was made on one end of the cylinder, in order to be able to measure, with the aid of a stroboscope, the exact revolution number of the cylinder. The ratio of increase from the engine was 7 : 1. The revolution number of the engine was measured by the customary revolution counter. A circular disk, dipping into machine oil, dampened the oscillations of the balance to which it

was attached.

3. Results of the experiments.- In carrying out the experiments, the model was placed in a definite position and the angle of attack was measured between the flat lower side of the wing and the horizontal wind direction. After the balance had been brought into equilibrium, the wind was started and the lift was measured, first with the cylinder at rest and then with it rotating.

The direct measurement of the revolution number of the cylinder by means of a stroboscope gave no reliable result. The stroboscope consisted of a disk with one or more axial slots, distributed regularly around the circumference, this disk being mounted on the axle of a small electric motor. The other end of the axis was connected with a revolution counter. The revolution speed could be changed by means of a rheostat. Although the image of the spot, seen through the stroboscope, could be brought to a standstill, this appeared possible at different revolution speeds, so that no reliable values could be determined.

Table I gives the values read on the revolution counter of the engine multiplied by 7. Since some slipping of the cord could be expected, the actual speed of the cylinder was probably somewhat slower.

It appeared that the curve, lift coefficient plotted against the angle of attack, was very unfavorable for the still cylinder and had, even at 0°, a very low maximum lift coefficient of 0.294 (0.302) (See Table I and Fig. 3).

Since it was possible to assume that this was caused alone by the shape of the cross-section and it had appeared from previous experiments that deviations from the smooth shape and that projecting parts could greatly diminish the maximum lift, so that the critical angle would be reached sooner (See Reports A 51 and A 39, "Verslagen en Verhandelingen R.S.L." Part II, pp. 1 and 13), it appeared that the slot between the cylinder and the rear portion, on the suction side of the model, might have an effect. In order to test this point, the slot was closed on the suction side with paraffin, the surface smoothened and the curve found anew. This resulted in a considerable improvement. The maximum lift coefficient, which was now found at a critical angle of 4°, was still very low (0.413), permitting the conclusion that the shape of the wing section was not favorable.

At all angles of attack, greater values were obtained with the cylinder rotating than with it at rest. The results are given both in tabular and in graphic form. It may also be remarked that most of the experiments were executed at a wind velocity of 16.7 m/sec., while the revolution speeds of the cylinder in most of the experiments were 3000, 8000 and 17000 R.P.M., corresponding respectively to peripheral velocities of 5.9, 15.8 and 33.5 m/sec. A few experiments were performed at both higher (20.4 m/sec.) and lower (11.8 m/sec.) wind velocities (shown only in the table, not in the graphs). No experiments were made with roughened cylinder surface.

The graphs show plainly that the lift coefficient is increased

by rotating the cylinder. Below the critical angle, the increase is about 10%, besides greatly increasing this angle. The curve falls off at the critical angle and then ascends toward a new and larger critical angle. From some of the tests, it may perhaps be deduced that the magnitude of the new critical angle is connected with the revolution speed of the cylinder.

Since the character of the curve for the rotating cylinder is entirely analogous to that of a wing with a wide slot, it may be concluded that the slot has no detrimental effect while the cylinder is rotating. (See Table II for the widths of the slot.)

In connection with other wind tunnel experiments, it was decided to discontinue these tests temporarily, in order to make various changes in the model. It is intended to continue the experiments, in order to obtain further and more accurate data.

4. General conclusions.- Although these preliminary results are still too few in number for giving any explanation of the facts and it is intended soon to continue the experiments systematically, a few general conclusions may be drawn.

In the first place the expectation seems to be fulfilled, that it is possible to produce considerable changes in the flow round about a wing by means of a rotating cylinder. These changes depend in part, on the revolution speed and their intensity can therefore be varied at will. Thus a mean is obtained for increasing our knowledge of the flow about bodies. Moreover, there appears the possibility of thus increasing the value of the lift coefficient,

which can be of practical importance. The difference above and below the critical angle of attack are of especial interest.

As regards the former portion of the curve, it can, however, be assumed that the decrease in the lift, from exceeding the critical angle, was due to an extension of the vortex field on the negative-pressure side of the airfoil. This vortex field is easily perceived, when the air flow is tested by introducing a fine wire attached to a metal needle.

It is then seen that the air flows back on the negative-pressure side near the trailing edge. If the cylinder is then rotated, without changing the position of the model, it is found that, at not too great angles (e.g., 2°), the turbulence entirely disappears. At greater angles of attack the extent of the vortex field is diminished. This phenomenon can be explained on the basis of the marginal layer theory mentioned in section 1.

The connection between the revolution speed of the cylinder, the wind velocity with respect to the airfoil, the roughness of the cylinder surface and the cross-section of the airfoil must be investigated through further experiments.

In agreement with this explanation, is the established fact that the curve reaches its highest point at 6° for 1500 R.P.M. (29 m/sec.), while it first reaches its highest point at 9.6° for 8000 R.P.M. (15.8 m/sec.). Even at the higher wind velocity of 20.4 m/sec., about the same coefficients are found for the stationary cylinder, while being much larger for the rotating cylinder,

although still smaller than at the wind velocity of 16.7 m/sec.

Likewise it appears that, while at 6° there is little difference between the lift at 3000 and at 8000 R.P.M. of the cylinder, at 8° angle of attack the lift coefficient for 3000 R.P.M. (5.9 m/sec.) is much smaller than for 8000 and 17000 R.P.M. This seems to be due to the fact that a certain minimum peripheral velocity of the cylinder is necessary, in order to improve the flow above the critical angle of attack.

Since the lift coefficient is 0.405 at 3000 R.P.M. and at a wind velocity of 20.4 m/sec. and hence much higher than the coefficient obtained with the cylinder at rest with the slot closed, it may be assumed that a small increase in the peripheral velocity (e.g., to 8 m/sec.) would suffice to cause the coefficient to increase to its maximum value. Hence it follows that, at 8° angle of attack and 16.7 m/sec. wind velocity, about 6 m/sec. peripheral velocity of the cylinder is necessary, while, at 20.4 m/sec. wind velocity, a peripheral velocity of about 8 m/sec. is required. The tests are yet too incomplete to go further into this matter now.

Below the critical angle the lift increase was about 10% at the peripheral velocities tested. The entire curve seems to be about evenly displaced. As to how far it shall appear possible to raise this portion of the curve by increasing the peripheral velocity of the cylinder must be determined by further experiments. Likewise, the value of this method of increasing the lift for practical purposes, by measuring the drag with a rotating cylinder,

must be further investigated.

5. Conclusions.- It is found that the flow of the air around an airfoil can be modified by introducing a rotating cylinder into its leading edge. This increased the lift in all the experiments, as well as the maximum lift.

Although further experiments, such as the determination of the drag and moments, pressure distribution on the upper surface and the flow velocity in the marginal layer, are necessary, in order to obtain a correct conception of what value the above-mentioned experiments shall have for both theory and practice, the importance of the possibility of modifying the flow about an airfoil has already been demonstrated.

Table I.

Wing model No. 38 (with rotating cylinder).

Wind velocity	Angle of attack	R.P.M. of cylinder	Peripheral velocity of cylinder	Lift coefficient		
				Cylinder at rest	Cylinder at rest with slot closed	Cylinder rotating
m/sec.	degrees		m/sec.			
16.7	- 2	--	--	0.249	0.245	--
16.7	- 2	3000	5.9	--	--	0.281
16.7	- 2	17000	33.5	--	--	0.284
16.7	0	--	--	0.302 } 0.294 }	0.302	--
16.7	0	3000	5.9	--	--	{ 0.332 0.333
16.7	0	17000	33.5	--	--	{ 0.343 0.335
11.8	0	--	--	0.310	--	--
11.8	0	3000	5.9	--	--	0.345
11.8	0	17000	33.5	--	--	0.354
16.7	+ 2	--	--	--	0.367	--
16.7	+ 4	--	--	0.274	0.413	--
16.7	+ 4	3000	5.9	--	--	0.449
16.7	+ 4	8000	15.8	--	--	0.455
16.7	+ 4	17000	33.5	--	--	0.456
16.7	+ 6	--	--	0.235	0.302	--
16.7	+ 6	3000	5.9	--	--	0.483
16.7	+ 6	8000	15.8	--	--	0.487
16.7	+ 6	17000	33.5	--	--	0.487
20.4	+ 6	--	--	0.234	--	--
20.4	+ 6	3000	5.9	--	--	0.461
20.4	+ 6	8000	15.8	--	--	0.467
20.4	+ 6	17000	33.5	--	--	0.469
16.7	+ 8	--	--	0.233	0.256	--
16.7	+ 8	1500	2.9	--	--	0.295
16.7	+ 8	3000	5.9	--	--	0.522
16.7	+ 8	8000	15.8	--	--	0.526
16.7	+ 8	17000	33.5	--	--	0.527
20.4	+ 8	--	--	0.232	--	--
20.4	+ 8	3000	5.9	--	--	0.405
20.4	+ 8	8000	15.8	--	--	0.501
20.4	+ 8	17000	33.5	--	--	0.502
16.7	+ 9.6	--	--	0.247	--	--
16.7	+ 9.6	8000	15.8	--	--	0.564
16.7	+12	--	--	--	0.267	--
16.7	+13	--	--	0.276	--	--

Table I (Cont.)

Wing model No. 38 (with rotating cylinder).

Wind velocity m/sec.	Angle of attack degrees	R.P.M. of cylinder	Peripheral velocity of cylinder m/sec.	Lift coefficient		
				Cylinder at rest	Cylinder at rest with slot closed	Cylinder rotating
16.7	+13	17000	33.5	--	--	0.371
16.7	+16	--	--	0.287	0.308	--
16.7	+16	12000	23.6	--	--	0.368
16.7	+16	17000	33.5	--	--	0.373

$R_y = C_y \frac{\gamma}{g} O V^2$

R_y = component of wind's force perpendicular to the relative direction of the wind (lift) in kg.

C_y = absolute lift coefficient.

γ = Sp. Gr. of the air in kg/m³

g = acceleration due to gravity, m/sec.²

O = wing area in m²

V = wind velocity in m/sec.

Table II.

With slot between cylinder and rear piece.

Distance (mm) from left end of wing	Width of slot in mm
0	0.3
250	0.3
500	0.2
750	0.3
1000	0.5

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

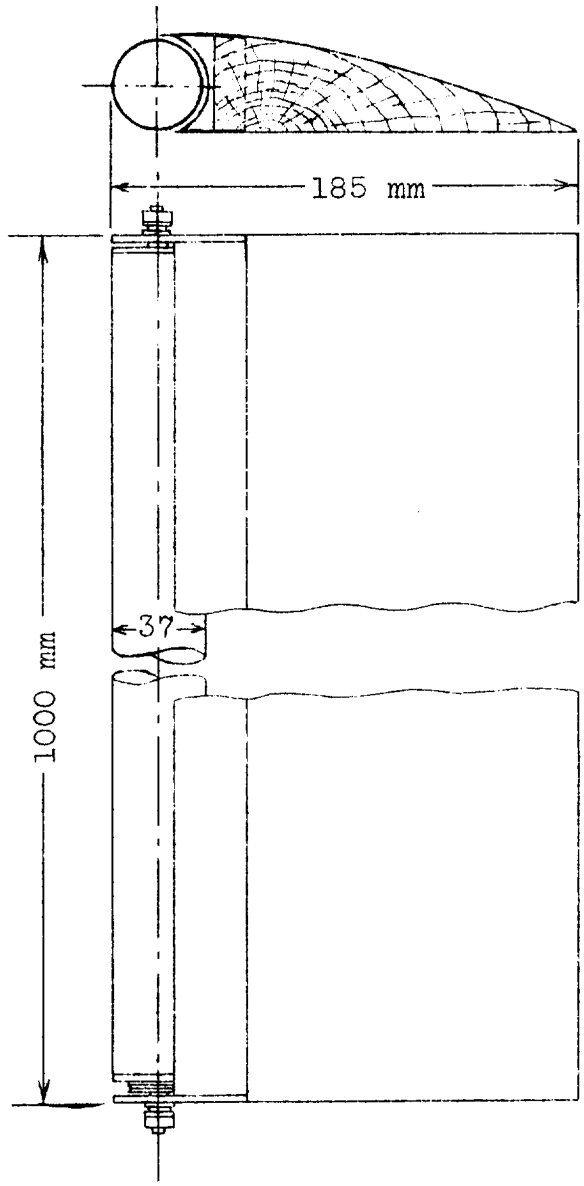
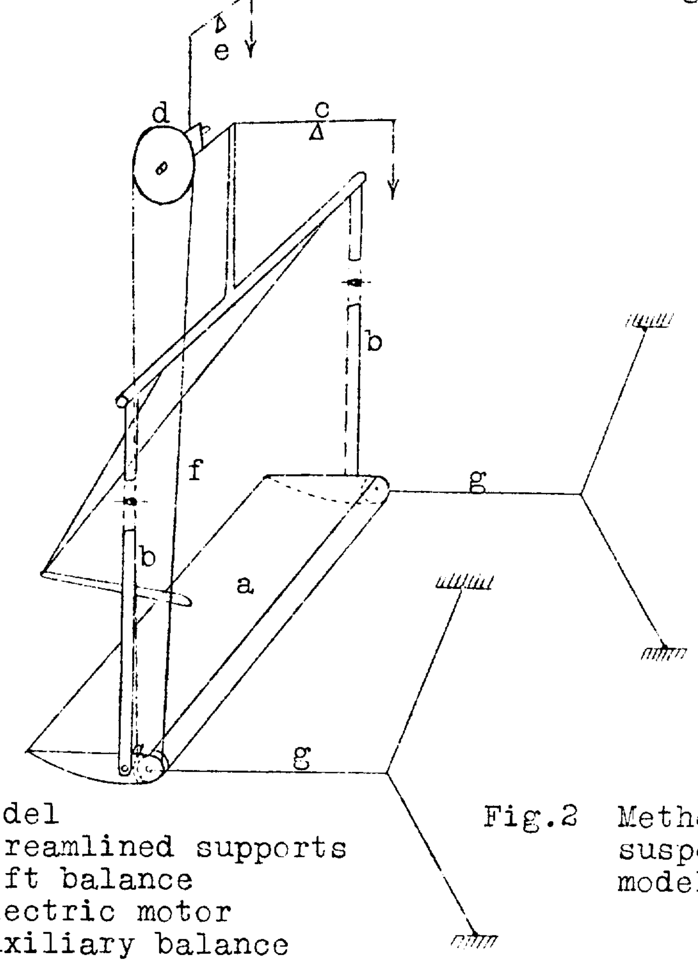


Fig.1 Wing model No.38,with rotating cylinder.



a = model
b = streamlined supports
c = lift balance
d = electric motor
e = auxiliary balance
f = driving cord
g = wires for offsetting the drag.

Fig.2 Method of suspending model.

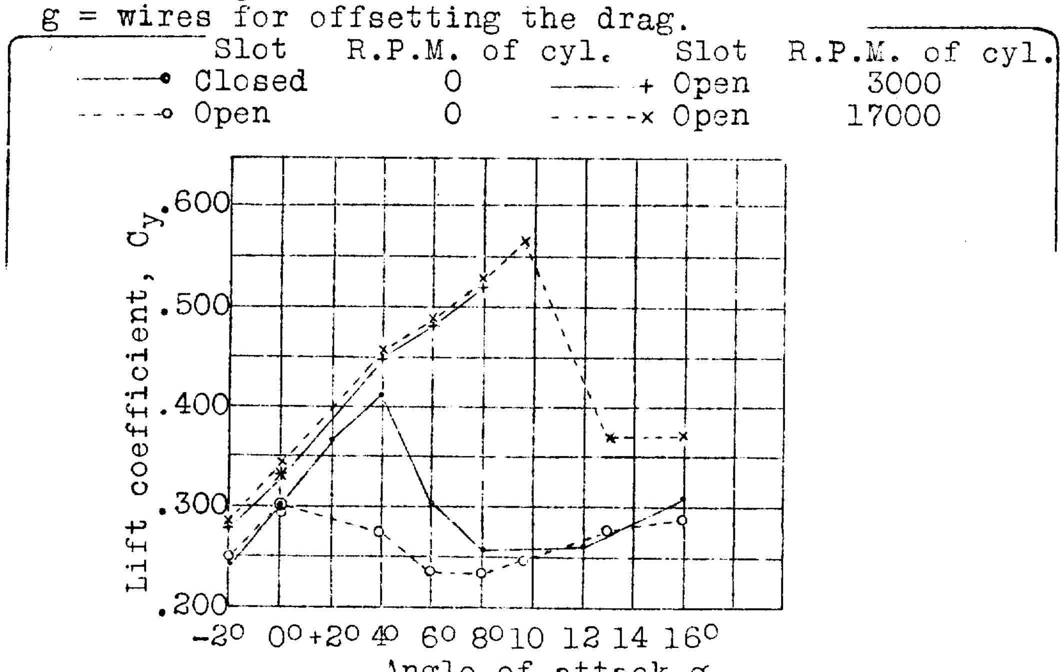


Fig.3 Lift coefficient C_y against angle of attack, α.